AD-770 596

COMPOSITE SHEAR STRENGTH - TUBE TORSION VS SHORT BEAM SHEAR

R. E. Lavengood, et al

Monsanto Research Corporation

Prepared for:

Office of Naval Research

October 1973

Security Classification

AD-770 596

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Monsanto Research Corporation	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Composite Shear Strength - Tube Torsion vs Short Beam Shear

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

R. E. Lavengood and M. J. Michno, Jr.

6. REPORT DATE October, 1973	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO. N00014-67-C-0218 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) HPC 73-155 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Office of Naval Research Washington, D. C.

13. ABSTRACT

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DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Mechanics						
Volume Fraction						
Reinforced Plastics						
Short Beam Shear						
Tube-Torsion						
Shear Strength						

COMPOSITE SHEAR STRENGTH -

TUBE TORSION VS. SHORT BEAM SHEAR

by

R. E. Lavengood
Monsanto Company
St. Louis, Missouri 63166

and

M. J. Michno, Jr.
Washington University
St. Louis, Missouri 63130

October, 1973

Monsanto/Washington University Association
High Performance Composites Program
Sponsored by ONR and ARPA
Contract No. N00014-67-C-0218, ARPA Order 876

FORWARD

The research reported herein was conducted by the staff of Monsanto/Washington University Association under the sponsorship of the Advanced Research Projects Agency, Department of Defense, through a contract with the Office of Naval Research, N00014-67-C-0218 (formerly N00014-66-C-0045), ARPA Order No. 87, ONR contract authority NR 356-484/4-13-66, entitled "Development of High Performance Composites".

The prime contractor is Monsanto Research Corporation. The Program Manager is Dr. Rolf Buchdahl (Phone 314-694-4721).

The contract is funded for $7,000,000 and expires 30 June, 1974.

Composite Shear Strength - Tube Torsion vs Short Beam Shear

R. E. Lavengood
Monsanto Company
St. Louis, Missouri

M. J. Michno, Jr.
Washington University
St. Louis, Missouri

ABSTRACT

Experimental evidence is presented for transversely isotropic glass-epoxy to show that shear strength determinations using the short-beam shear method (ASTM D2344-67) agree well with the results of tube torsion for a certain volume fraction range. In all cases short-beam shear results bound tube torsion results from below. Comparison of short beam and tube torsion shear strength may be a convenient measure of fabrication effectiveness.

Composite Shear Strength -
Tube Torsion vs. Short Beam Shear

INTRODUCTION

Shear strength is one of the most important material properties to be considered when designing components with composites. The experimental determination of composite shear strength has therefore received considerable attention. Many specimen configurations are available [1] for shear strength testing but the two most widely employed are the unidirectionally reinforced short beam and hoop-wound tubular configurations.

Thin-walled hoop-wound tubes subjected to simple, axial torsion are unequivocally the best specimens for determining the shear strength of a material [2], [3]. A uniform state of shear exists in such a tube and the stress level is easily computed from knowledge of the applied torque and the geometry (e.g. the wall thickness and mean radius). In principle, the required state of pure shear stress also exists along the neutral plane of a simply supported beam with a central load. The failure of such specimens however may occur in flexure, shear, or a mixed mode [4]. A relatively low span-to-depth ratio is required to assure a shear failure. The test procedure detailed in ASTM D2344-67 generally results in the desired failure mode.

The importance of material variables such as fiber volume fraction and void content on short beam shear tests has been studied by Mullin and Knoell [4]. Other investigators [5,6,7]

have studied the effect of beam geometry and deformation under the loading nose. In general, these investigators conclude that the SBS method should be used only as a screening test and where precise measurements of shearing strength are required, more expensive tube torsion experiments should be used. The wide discrepancy in the short beam shear and tube torsion data presented in [8] for graphite-epoxy and boron-aluminum seems to support the above conclusion. In contrast, the numerical results presented in [4] - [7] for a unidirectional reinforced short beam indicate that with proper selection of beam geometry in light of materials properties, and with sufficient experimental care the short beam shear results should closely agree with those of tube torsion.

This dilemma may result from the fact that the two shear tests measure different quantities. Fig. 1b & 1c shows that the tube torsion test produces a uniform shear stress in the 1-2 plane. This ultimately results in a crack forming in the 1-3 plane. The short beam shear test produces a much more complex pattern of stresses, but near the midplane of the beam, the dominant stress is shear in the 1-3 plane. In a properly executed test this results in a crack forming in the 1-2 plane. clearly, if the results of the two tests are to be similar, the first requirement is that the material be transversely isotropic (i.e. $\tau_{13}^{ult} = \tau_{12}^{ult}$). This is usually assured in filament wound materials, but is subject to question in materials prepared from prepreg sheets.

The specimens used in this study were all prepared by wet winding to insure transverse isotropy. This permits a valid comparison of the two tests over the range of volume fractions normally encountered in practical composites.

Materials and Specimens

All specimens were wound on steel mandrels with Pittsburgh Plate Glass 1062-T6 E glass fibers and Shell Epon 828 resin cured with 20 phr* curing agent Z. Volume fraction was controlled by varying the winding tension. After winding, the specimens were vacuum impregnated at 60 to 70°C for 20 minutes to reduce voids. The mandrels were then rotated until the resin gelled. The final cure was in a 150°C air circulating oven for 2 hours.

Both the tubes and the NOL rings were then ground to final dimensions. Finished tubes were 8 to 10 inches long with a mean diameter of 1 inch and a wall thickness of about 0.050 inches. The NOL rings had a 6 inch outside diameter, 0.125 inch thickness and 0.250 inch width. Short beam shear specimens were cut from these rings in accordance with ASTM D2344-67.

The fiber volume fractions were determined by burning broken samples and ranged from 25 to 74 percent in the short beam shear samples and 42 to 72 percent in the tubes. Void content of the samples was determined in accordance with ASTM

*phr = parts per hundred resin

Standard D2734-26 Results indicated that less than 1% voids were present.

Apparatus and Experimental Technique

SBS samples were tested to failure in an Instron Universal Testing Machine using the shear test fixture detailed in ASTM D2344-67. The cross-head rate was .05 in/min. which resulted in failure within 4 to 6 minutes. Load vs. time curves were recorded. The shear strength (S) was calculated from the simple strength of materials formula:

$$S = \tau_{13}^{ult} = \frac{3}{4}\frac{P}{bd} \qquad (1)$$

where P = load at break

b = specimen width

d = specimen depth

Tube torsion tests were conducted on a MTS closed loop servo-controlled testing machine. The specimens were carefully aligned and run to failure in 4-6 minutes with a constant rate of rotation. A recording of torque vs. time was made. The shear strength (S) was calculated from the maximum torque (T) and the specimen geometry:

$$S = \tau_{12}^{ult} = \frac{T}{2\pi r^2 t} \qquad (2)$$

where r = mean radius

and t = wall thickness.

Test Results and Discussion

A total of 146 short beam shear tests and 11 tube torsion tests were run. Results are tabulated (Table 1) and presented

in graphic form (Fig. 2). Shear strength, S, vs. fiber volume fraction was fitted to the best straight line using the least squares technique. The bands associated with the short beam shear data points in Fig. 2 represent plus and minus one standard deviation. The relatively small standard deviations indicate very high specimen uniformity. The data points at 25 and 36.5 volume percent were excluded in this fitting process.

Short Beam Shear

As noted in Table 1 and Fig. 2 for specimens with these two volume fractions, the failure mode was flexural (i.e. tensile) and the shear strength reported is the apparent shear strength. The failure for all other volume fractions was clearly a horizontal shear failure along the neutral axis of the beam. Initiation of a shear failure was clearly audible, began at mid-span and propagated to the right or left with no preference.

The equation of the best fitting straight line to the SBS data in the region v_f = 38-75% was found to be

$$S = -1.46 v_f + 10.91 \text{ (ksi)} \quad \text{with standard deviation} = 0.25 \text{ (ksi)} \tag{3}$$

Tube Torsion

Tube torsion results also show decreasing shear strength with increasing volume fraction. The best fitting linear relationship was found to be

$$S = -4.64v_f + 13.27 \text{ (ksi)} \tag{4}$$

with standard deviation = 0.61 (ksi)

Generally in the range $38\% \leq v_f \leq 55\%$, the results of the short beam shear tests lie below the shear strength as determined by tube torsion. However, in the range $55\% \leq v_f \leq 75\%$ the two agree quite well.

Shear-Tensile Transition in Bending Tests

The tensile failure of "short beam shear" specimens can be anticipated by a strength of materials analysis. In such a test, the maximum shear stress acts on the neutral plane of the beam and at the midsection and is given by

$$\tau = \frac{3}{4}\frac{P}{bd} \tag{1a}$$

The maximum tensile stress is at the midpoint of the face of the specimen. These stresses could lead to either compressive failure under the loading nose or tensile failure on the opposite face. The former is frequently inhibited by the loading nose, so the latter is more common. This tensile stress is given by

$$\sigma = \frac{3}{2}\frac{P\ell}{bd^2} \tag{5}$$

Following the presentation given in [4], the critical transition point between tensile failure and shear failure can be determined, as a function of the span-to-depth ratio and material properties by dividing Equation (1a) by Equation (5).

Thus

$$\frac{\tau^{ult}}{\sigma^{ult}} = \frac{1}{2(\ell/d)} \tag{6}$$

describes the critical geometry for a given material. The ASTM standard procedure used in this study has effective (ℓ/d) ratio of about 4. It follows that the tensile strength of the material must be more than eight times the shear strength, to assure the desired failure mode in this test. These strengths both depend on fiber volume fraction. Tensile strength of the glass-epoxy material used in this study is given by

$$\sigma^{ult} = 225.5v_f + 6.68 \text{ (ksi)} \tag{7}$$

Using the above and Equation (4), which relates shear strength to volume fraction, the volume fraction at the transition point is 38 percent. At this volume fraction, the maximum shear stress at failure is 11.50 ksi and the maximum tensile stress is 92.37 ksi. This gives an equal probability of failure in shear at the midplane or in tension on the lower face of the beam. Higher fiber content would increase the tensile strength, thus leading to shear failure; while lower fiber loadings will result in tensile failure. This is consistent with the experimental results.

Conclusions

1. In the range of 50 to 70 volume percent fibers, the results of the two different tests are in good agreement. This is the range of greatest practical interest and throughout the

short beam shear test tends to be slightly lower than the corresponding torsion tube results. From an engineering standpoint that means that with the transversely isotropic composites, short beam shear results are a good estimate of the true shear strength of the material. Differences are in the conservative direction.

2. Some care must be exercised when short beam shear testing materials have low tensile strength. This might result either from low fiber volume fraction or from weak fibers. A low tensile strength might lead to tensile fracture on the lower face of the beam rather than the desired shear failure. Such an occurrence can be easily detected by visual examination of the broken specimen.

3. The close agreement between the short beam shear and tube torsion tests on this transversely isotropic material coupled with the diverging results found by investigators working with laminated composites suggests that the ratio of the two results would be a good measure of fabrication efficiency.

Acknowledgment

The authors express their appreciation to A. Hargrove and W. Neff for their assistance with the experimental phase of this study.

The work described in this paper, contribution HPC-72-155 is part of the research conducted by the Monsanto-Washington University Association sponsored by the Advanced Research Projects Agency, Department of Defense, under Office of Naval Research Contract No. N00014-67-C-0218, formerly No. N00014-66-C-0045.

TABLE 1

SHEAR STRENGTH TEST RESULTS

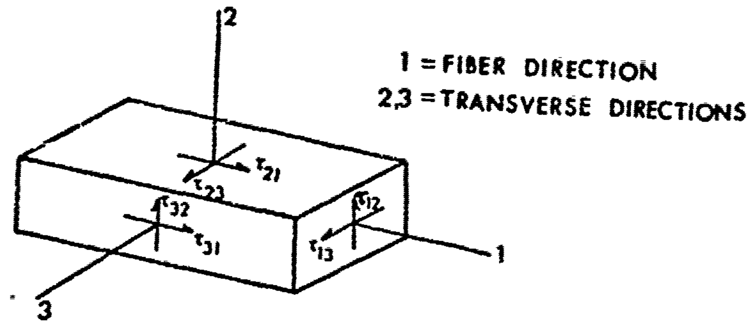
SHORT BEAM SAMPLES

v_f(%)	Number of Tests	Apparent Shear Strength S(psi) (Average)	Standard Deviation(psi)
25	19	8,320*	360
36.5	21	9,500*	420
44	17	10,400	480
49	12	10,000	450
57	20	9,640	460
62.5	18	10,300	270
66	20	9,820	460
74	19	9,710	340

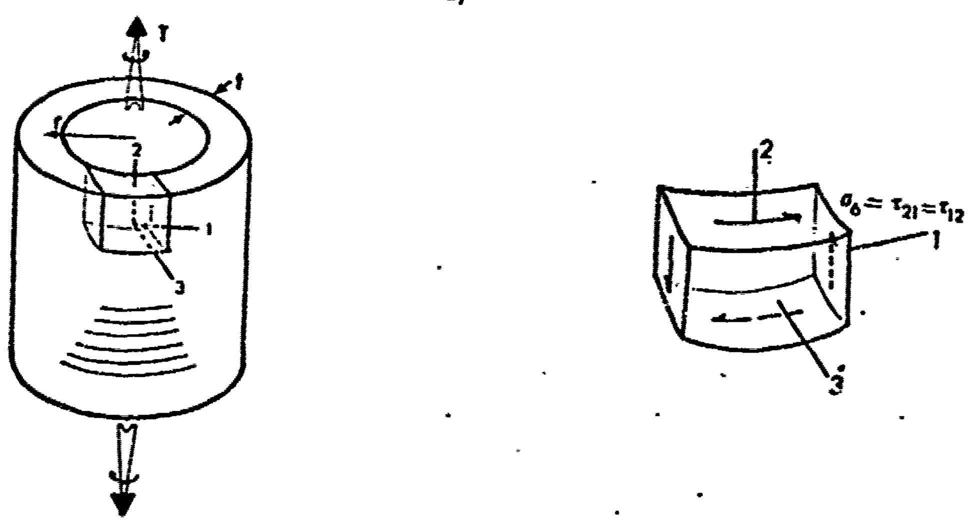
*Tensile Failure Mode

TUBULAR SAMPLES

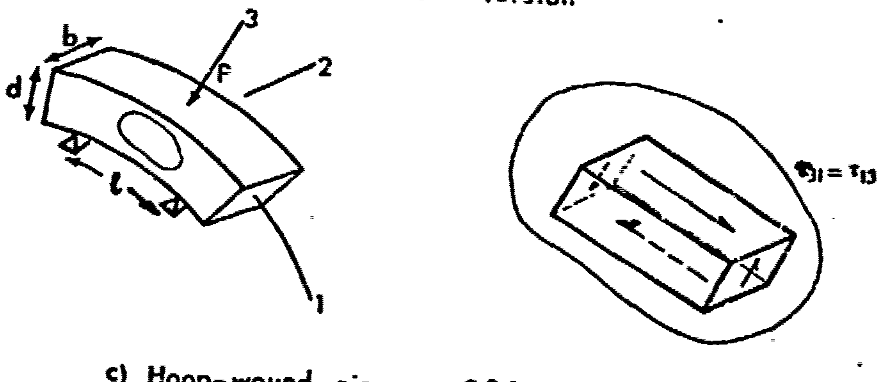
v_f(%)	S(psi)
42	11,390
43	10,700
43	11,200
44	10,980
58	11,580
60	11,340
64	10,940
66	9,430
70	9,310
71	9,720
72	9,690



a)



b) Hoop-wound tube — Torsion



c) Hoop-wound ring — SBS

Fig. 1. Shear-Stress Geometry

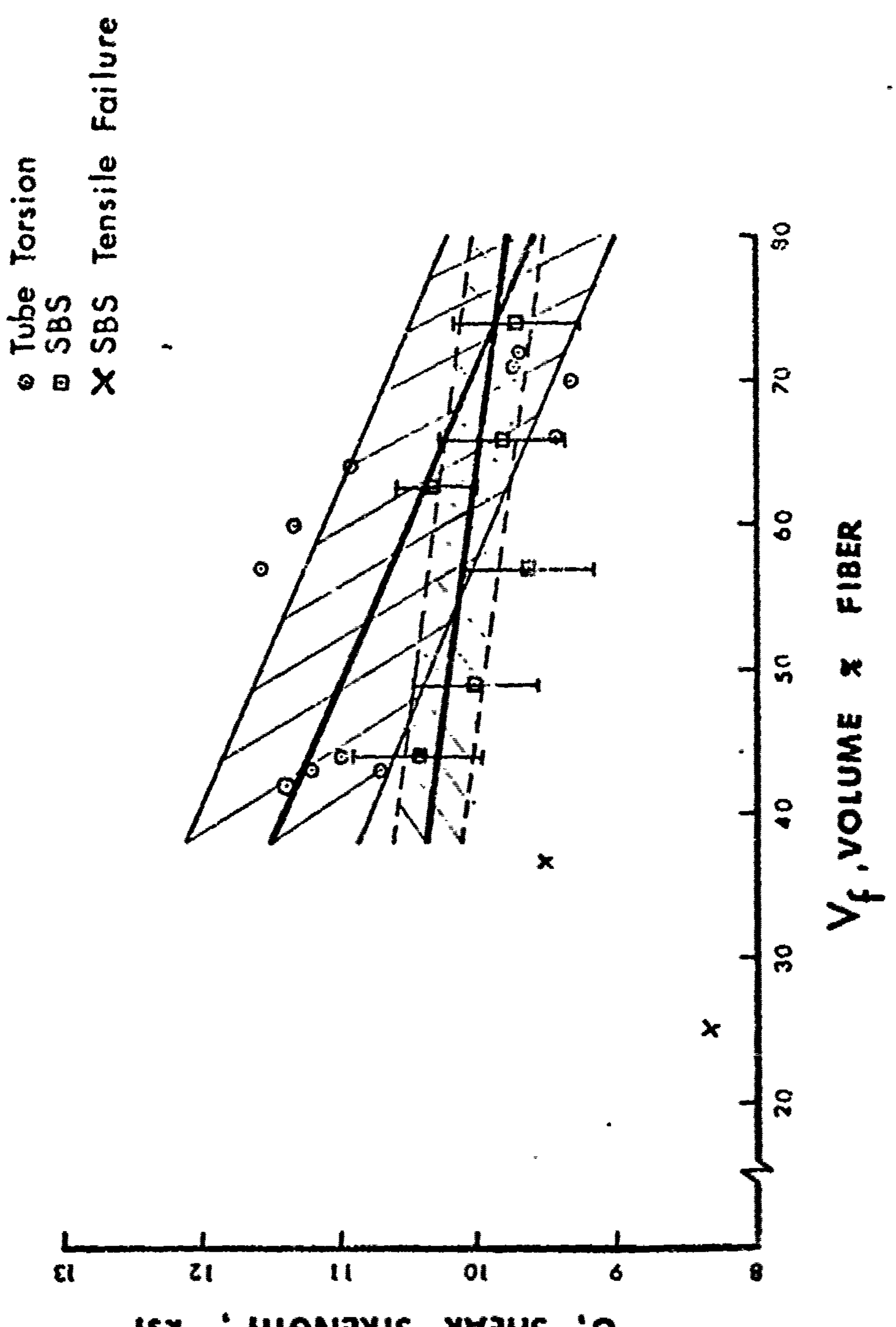


Fig. 2. Shear Strength vs. Volume Fraction

REFERENCES

1. Adams, D. F. and Thomas, R. L., "Test Methods for the Determination of Unidirectional Composite Shear Properties," Proceedings of the Twelfth National SAMPE Symposium - Advances in Structural Composites, Oct. 1967 (See also)
Adams, D. F. and Thomas, R. L., "The Solid-Rod Torsion Test for the Determination of Unidirectional Composite Shear Properties" Textile Research Journal, Vol. 39, No. 4 pp 339-345, April 1969.

2. Halpin, J. C., Pagano, N. J., Whitney, J. M. and Wu, E. M., "Characterization of Anisotropic Composite Materials", Composite Materials: Testing and Design; ASTM/STP 460, American Society for Testing and Materials, pp 37-47, 1969.

3. Pagano, N. J., "Observations on Shear Test Methods of Composite Materials", Technical Memorandum MAN 67-16, AFML, Sept. 1967.

4. Mullin, J. V. and Knoell, A. C., "Basic Concepts in Composite Beam Testing", Materials Research and Standards, pp 16-33, Dec. 1970.

5. Sattur, S. A. and Kellogg, D. H., "The Effect of Geometry on the Mode of Failure of Composites in Short-Beam Shear Tests", Composite Materials: Testing and Design, ASTM STP 460, American Society for Testing and Materials, pp 62-71, 1969.

6. Kedward, K. T., "On the Short Beam Test Method" Fibre Science and Technology. 5, pp 85-95, 1972.

7. Berg, C. A., Tirosh, J. and Israeli, M., "Analysis of Short Beam Bending of Fiber Reinforced Composites", Composite Materials: Testing and Design (Second Conference), ASTM STP 497, American Society for Testing and Materials, pp 206-218, 1972.

8. Adsit, N. R., McCutchen, H., and Forest, J. D., "Shear Testing of Advanced Composites", Proceedings, Sixth St. Louis Symposium on Composite Materials in Engineering Design, (in press), paper 9-4 1972.